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Human robot collaboration - using kinect v2 for ISO/TS 15066 speed and separation monitoring

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Abstract

The use of industrial robots within assembly workstations where human and robot should be able to collaborate or even cooperate involve high safety requirements. One out of four possibilities outlined in the current technical specification ISO/TS 15066 for ensuring safety is speed and separation monitoring. Here the robot motion speed in- or decreases dynamically depending on the distance between operator and robot.
This paper introduces an approach of a speed and separation monitoring system with the help of a time of flight sensing. After introducing this safety ensuring method, a Microsoft Kinect V2 is used to continuously detect human worker within a shared workspace. With the help of the robots joint angles from the robot control it is possible to compute the distances between all robot joints and the human worker. The shortest distance, which is at the same the critical distance time, is determined and as a consequence the velocity and acceleration values of the robot were set to safe values according to ISO/TS 15066. As it is not necessary to visually detect also the robot, but only human workers, this approach is very resilient. Afterwards the introduced setup is tested by a real detected human in front of a Kinect and a simulated industrial robot (Universal Robot UR5) in the robot operating system ROS. Measurements show that depending on the position of the worker the robots speed adapts to recommended safety values up to a complete halt if necessary. Conclusively all results are discussed and an outlook for possible fields of applications is given.

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Keywords: human robot collaboration, safety, ISO/TS 15066, kinect v2

1. Introduction

1.1. Motivation

The increasing trend of human robot collaboration in the last few years mainly take place in the field of assembly applications [1]. New technologies enable human workers to be supported by industrial robots. A study of the german Fraunhofer Institute IAO found out that over 70 percent of the applications with human robot collaboration are in the assembly area. And ”*in the majority of cases the applications involve a form of coexistence in which the humans and robots only occasionally share the same workspace*” [2]. Typical fields of applications are assembly applications, lick pick and place operations, mounting, joining or part handing. All these use cases have in common that the conventional protective measure of a separating guard must be removed. Current implementations use so called intrinsically safe lightweight robots to comply latest safety standards. Nevertheless, additional safety measures are usually necessary to minimize the risk of collisions between human and robot. In this paper we present an approach where the safety complying operation mode speed and separation monitoring is realized with the help of skeleton tracking with a time of flight sensor. By combining both, real time human tracking and out of the robot control known joint positions, we determine the shortest separation distance to derive a safety complying robot motion speed. The logical interaction of the entire system setup is schematically represented in fig. 1. The implementation of such an approach can lead to the fact that, in addition to the use of safe robots, it is also possible that already existing small industrial robots can be considered for collaborative applications. The advantage of this lies in the potentially higher payloads.

1.2. Fundamentals

First of all we present some background information to introduce the basic parts of this papers approach. We shortly describe safety within industrial robots and furthermore the later used principle of time of flight measuring.

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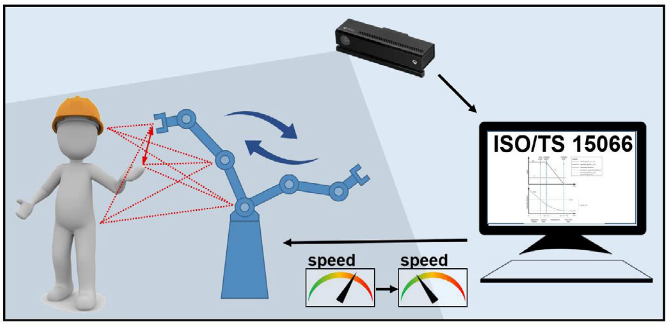

Fig. 1: overview of the entire system setup

1.2.1. Safety in Industrial Robotics

Before putting an industrial robot into operation a risk assessment for ensuring human safety has to be done. Basic safety requirements for robots can be found in ISO 10218-1/2 [3,4]. Because of the fact that they cover collaborative operations of human workers and industrial robots only minimally, the International Organization of Standardization supplemented these requirement with the technical specification ISO/TS 15066 [5] in 2016. This specification subclassifies four different collaborative operation modes:

- safety-rated monitored stop,
- hand guiding,
- power and force limiting, and
- speed and separation monitoring.

In this paper we chose speed and separation monitoring. Here human and robot share a collaborative workspace and in principle a physical contact may occur. An overview of all combinations of possible contacts between human and robot is shown in fig. 2, in detail between one robot joint any all human joints one the left, and one human joint and all robot joints on the right.

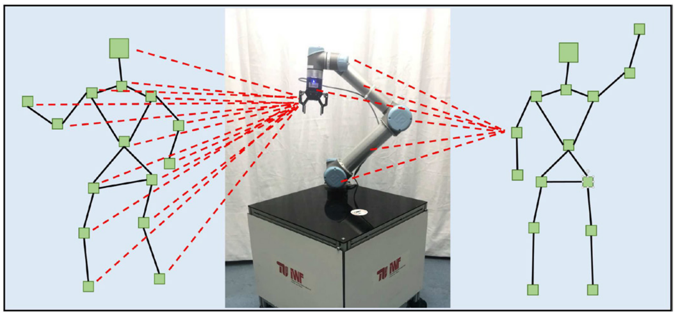

Fig. 2: possible joint contact combinations

To reduce this risk the robot motion speed has to de- or increase dynamically, depending on the distance between human and robot. If the distance gets below a minimum separation distance the robot initiates a safety-rated, emergency stop.

1.2.2. Time of Flight

Time of flight is a method for indirect distance measuring. It is based on a travel time measurement of a radiated and reflected signal whose speed is known. As shown in fig. 3 within the continuous-wave method multiple samples were measured, each phase-stepped by 90 degrees. Each sample generates four electrical charges $Q_1 - Q_4$ from the reflected light.

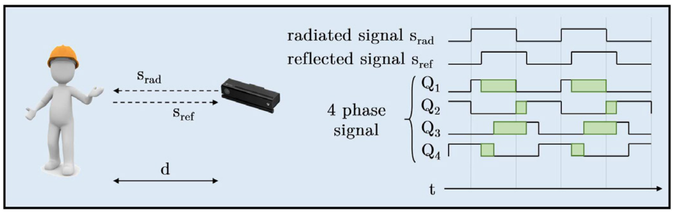

Fig. 3: time of flight: continuous-wave method

With the light speed c and the frequency f of the radiated signal, the phase angle ϕ between illumination and reflection and the distance d can be calculated as follows:

$$d = \frac{c}{2f} \cdot \frac{\phi}{2\pi} \tag{1}$$

$$\phi = \arctan\left(\frac{Q_3 - Q_4}{Q_1 - Q_2}\right) \tag{2}$$

1.3. Related Work

To achieve safety in a human robot collaborative shared workspace has been researched several times in the past few years. Within that various approaches have been presented to the scientific community. Present work like [6] dealt with a trajectory-dependent dynamic speed and separation monitoring to ensure safety. Another approach [7] used a multiple Kinect V1 setup, to sense both humans and robots movement, to subsequently derive safe robot motions. [8] also introduced a depth space approach, where depth space data is used generate repulsive vectors to adjust the robots joint velocities within the robot control. Latest approaches on the concrete method of speed and separation monitoring investigated the analytic determination of the protective separation distance S_p in detail, taking into account the speed of human or robot, the reaction time, the resulting breaking distance and others. In [9] speed and separation monitoring is realized within a simulation environment. By simulating both, human and robot, within an exemplary assembly task, the minimum protective distance gets determined for the whole process. [10] uses laser scanners to detect position and velocity of humans within the robot workspace and computes the safe separation distance based on the robots reported position and velocity. Another approach [11] realizes the human detection by a ladar sensor. These approaches are connected to complex hardware and cannot differentiate whether a detected moving object is a human or an object.

2. Method

This paper deals with the collaboration scenario of coexistence of humans and robot in the same workspace. A cooperation in which humans and robots have to interact is not intended. Besides, the robot can only be reached by humans from one side. These limitations are applied, for example, in an assembly process in which the robot performs simple tasks such as screwing together variable components, individually supplied and positioned by a human worker. In this approach we determine the real distance between human and robot by tracking the human worker with the help of a Microsoft Kinect V2. This low cost camera has an integrated time of flight sensor which is used to generate 3D position date of the human worker continuously. The Microsoft Kinect V2 has 60° vertical and 70° horizontal field of view and its range of detection is $0.5m - 4.5m$ far. Current industrial robots designed for collaboration have reaches between $500mm$ (Universal Robots UR3) up to $1423mm$ (Kuka KR 5 SI). Mounted near to the robots base or the worktop it is possible to observe one approach direction meaningfully. Such an arrangement will also ensure a best possible skeleton tracking. In general, the positioning of the Kinect V2 is relatively free as long as it can be transformed to the robot base coordinate system within an initial measuring. The suitability of this camera has been proofed in previous work like [12,13]. The skeleton tracking is done in concrete with the help of a modified skeleton tracker NiTE2, a middleware library for OpenNI. All algorithms parts respectively functions are separated into modules, so called nodes, orchestrated by the robot operating system ROS [14]. As interface to ROS *libfreenect2* [15] is used. Moreover the Kinect V2 has an additional RGB sensor, which can be used for visualization purposes. The overall architecture, as illustrated in fig. 4, enables us to change single functionalities in case of necessity, e.g. for experimenting various algorithms or even different hardware components.

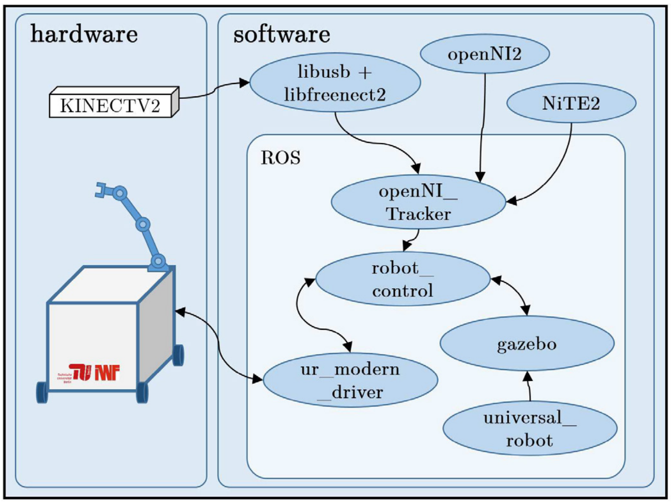

Fig. 4: system architecture

A central unit, which we call robot_control, now transforms all robot joint values $\vec{q}_{robot}$ out of the robots control and all tracked human joints $\vec{q}_{human}$ into a common coordinate system. Combined with the known coordinates of the robots base, real or simulated, it is possible to determine all distances $\vec{d}_{human \leftrightarrow robot}$ of all combinations between human and robot joints. The minimum of all these distance we call the critical distance d_{crit}. Subsequent d_{crit} is used as the input variable to compare it with the current protective separation distance S_p and adjust the maximum robot speed $v_{max,robot}$ to ensure a sufficient separation distance between human worker and robot. If needed, the robots motion speed gets decreased, at worst up to a emergency stop. If d_{crit} is large enough, we increase the robots speed. If the skeleton tracking is interrupted, e. g. by a hiding object, an emergency stop gets initiated. The basic overall procedure of this approach is represented in algorithm 1.

Algorithm 1: determination of d_{crit} and $v_{max,robot}$

```
Result: scaled robot motion speed depanding on human
        robot separation distance
Input  : $\vec{q}_{robot}$
Output: $d_{crit}$, $v_{max,robot}$
while kinect run do
    track skeleton
    $n_{scale} := 0.0$
    if skeleton = detected then
        determine human joint poses $\vec{q}_{human}$
        transform $\vec{q}_{human,kinect}$ to $\vec{q}_{human,world}$
        transform $\vec{q}_{robot}$ to $\vec{q}_{robot,world}$
        determine all joint combination distances
         $\vec{d}_{human \leftrightarrow robot}(\vec{q}_{human,world}, \vec{q}_{robot,world})$
        $d_{crit} := \min\{\vec{d}_{human \leftrightarrow robot}\}$
        if $d_{crit} \overset{!}{\leqslant} S_p$ then
            sysout ”separation distance to low”
        else
            determine $n_{scale}(d_{crit})$
        end
    else
        sysout ”human tracking failed”
    end
    $v_{max,robot} := v_{curr} \cdot n_{scale}$
end
```

3. Results

First, measurements were taken to verify a robust human tracking, which is the base of this approach's human robot distance determination. At a frame rate of approximate $15Hz$ it was possible to track the human worker robustly. Within that it we could measure 11 joints, from the hip upwards to torso, neck, shoulders, ellbows, hands and the head. For each of the 11 tracked body parts the distance was logged. In this case we mounted the Kinect V2 at the robots end effector to easily measure the distance between human and the robots tool center point. With raised arms held high we moved towards the robot, as schematically as shown on top in fig. 5. The measurement results are shown below. For safety reasons we determined the distance to a virtual robot model simulated in ROS.

After the validation of a robust human robot distance determination, the correct causality between separation distance and the robots speed was investigated. For this purpose a human worker has been tracked by the Kinect. The robot motion (containing its velocity depending on the separation distance) was simulated with MoveIT [16] within ROS. For investigating the speed adjustment a linear scaling of v_{robot} has been implemented. The scale factor n_{scale} depends on the current determined distance d_{crit} and gets computed as described in eq. 3. The dashed line in fig. 6 shows the estimated distance between human and robot. The continuous line represents n_{scale} and results of an assumed linear progression between the limits of $d_{nmin} = 0.85m$ and $d_{nmax} = 1.70m$. As thresholds were initially chosen at least one complete robot arm length (Universal Robot UR5 $= 0.85m$) as lower separation distance limit, and

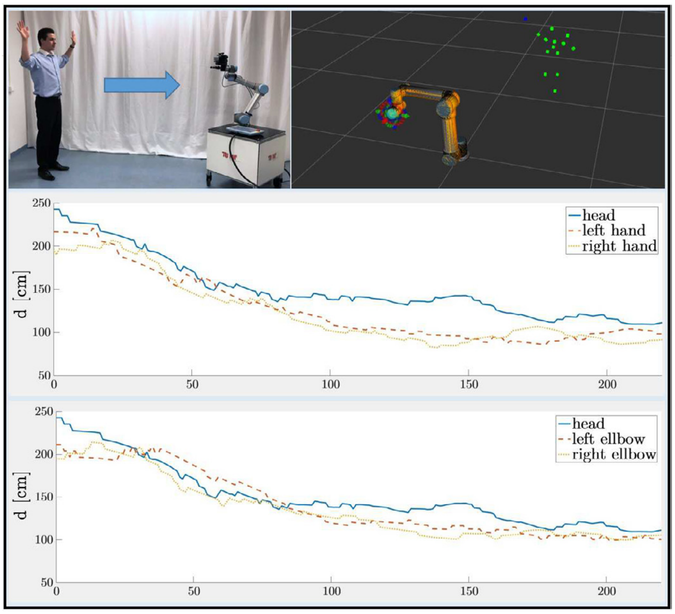

Fig. 5: human tracking and distance measuring

two robot arm lengths as a safe upper limit. These thresholds can be adjusted according to other robots or changing safety requirements.

$$n_{scale}(d_{crit}) = \begin{cases} 0, & \text{for } d_{crit} < 0.85m \\ \frac{1}{d_{nmax}-d_{nmin}} d_{crit} - 1, & \text{for } d_{crit} \in [d_{nmin}, d_{nmax}]m \\ 1, & \text{for } d_{crit} > 1.70m \end{cases} \tag{3}$$

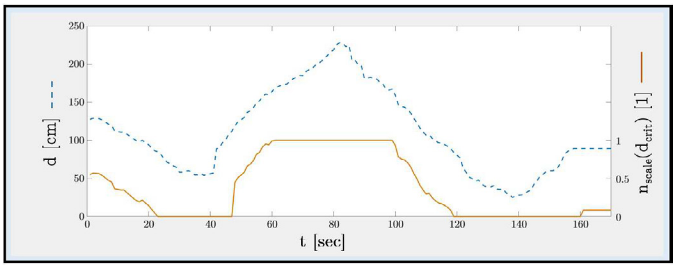

Fig. 6: scaling factor v_{scale} depending on $d_{human\leftrightarrow robot}$

4. Conclusion

The present work introduces an approach for ensuring safety within human robot collaboration by realizing ISO/TS 15066's method speed and separation monitoring. The basic idea is to adapt the robot speed depending on the distance between human and robot only by skeleton tracking the human worker. It is not necessary to differentiate between other objects or obstacles which are possibly intended to be contacted by the robot. The results showed that a robust human skeleton tracking setup with a Kinect V2, as realized in this paper, can be utilized for deriving safety ensuring values like robot speed. Based on the distance measurements to a virtual robot, which is simulated within ROS, a robot speed scaling factor is derived, varying between the full robot velocity up to an emergency stop. The overall system presented enables a human worker to operate within a workspace shared with one or in perspective several industrial robots. As future work it is planed to benchmark the accuracy of measuring with an available high-precision motion capturing system (Vicon). Furthermore the maximum robot speed may also be determined depending on the relative movement direction of human and robot. Investigations on multiple Kinect V2 setups for minimizing concealments or other skeleton tracking disturbances should improve the safety functionality of the entire setup.

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